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## Tools for Regional Sediment Management

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**PURPOSE:** This Coastal and Hydraulic Engineering Technical Note (CHETN) describes tools that have been adapted to assist with Regional Sediment Management (RSM) activities at the U.S. Army Engineer Districts, Mobile and New York. Geographic Information Systems (GIS) designed for RSM in the Mobile District, and numerical models that have been adapted for regional studies within the New York District are discussed.

**BACKGROUND:** Rosati et al. (2001) contains background information on RSM goals and procedures. Some of this information is briefly reproduced for continuity herein.

RSM refers to the effective utilization of littoral, estuarine, and riverine sediment resources in an environmentally effective and economical manner. RSM strives to maintain or enhance the natural exchange of sediment within the boundaries of the physical system. RSM changes the focus of engineering activities within the coastal, estuarine, and riverine systems from the local, or project-specific scale, to a broader scale that is defined by the natural sediment processes and may include the entire watershed. Implementation of RSM recognizes that the physical system and embedded ecosystems are modified and respond beyond the formal dimensions and time frames of individual projects. The larger spatial and longer temporal perspectives of RSM, as well as the broad range of disciplines with a stake in RSM projects, require partnerships with and co-leadership of RSM initiatives by the stakeholders. Decisions concerning the timing and scope of projects that move or utilize sediment must be made within an understanding of the regional system.

The Corps' National RSM Demonstration Program began in the Mobile District in October 1999. Separately, the grassroots movement for RSM grew with Corps Districts pursuing RSM initiatives with State and local partnerships. In late 2000, the National RSM Demonstration Program expanded to include five additional demonstration sites, in U.S. Army Engineer Districts, Jacksonville, Philadelphia, New York, Detroit, and the South Pacific Division. The National Demonstration Program has initially been focused on coastal sediment management, as discussed in this CHETN, although RSM encompasses the entire watershed

**GEOGRAPHICAL INFORMATION SYSTEMS FOR RSM:** The Spatial Data Branch, Operations Division, of the Mobile District, created a GIS to address the data management and data analysis requirements of the RSM Demonstration Program undertaken by the District. The resulting GIS provides those interested in and working towards RSM an interface to hydrographic, topographic, photogrammetric, and historic dredge material data for the RSM Demonstration Region, as well as custom applications designed to facilitate engineering analyses. The RSM GIS serves as the link between engineering analyses and regional numerical models. To date, development of the RSM GIS has included: input of spatial data for the RSM

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>JUN 2001</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2001 to 00-00-2001</b>	
4. TITLE AND SUBTITLE <b>Tools for Regional Sediment Managment</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>U.S. Army Engineer Research and Development Center,Vicksburg,MS,39180</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>17</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

region, use of built-in ArcView applications to enhance data manipulation and display, and creation of custom applications to extend the utility of ArcView for RSM specific goals. This section will give an overview of the effort to create the RSM GIS including data preparation for inclusion in the GIS, data display using ArcView, creation of custom applications for RSM, and other capabilities currently under development.

**Spatial Data Input:** Spatial data that are currently included in the RSM GIS include: hydrographic and topographic survey data, aerial and oblique photography, dredge material records, digital nautical charts, and generic GIS information.

**Hydrographic and topographic survey data.** Hydrographic and topographic survey data are required for the RSM Demonstration Program in two forms. First, a unique data set must be created for each survey collected in the region. Second, the data sets must be merged into a single most recent, or baseline data set that covers the entire region. The RSM GIS data sets include three types of hydrographic and topographic data: singlebeam echosounder data, multibeam echosounder data, and airborne Light Detection and Ranging (LIDAR) bathymetry and topography.

The most extensive data set used to create the RSM baseline data set was obtained from National Geophysical Data Center (NGDC). These data are the data that appear on National Oceanographic and Atmospheric Administration (NOAA) nautical charts and are the result of several years of hydrographic surveying. The NGDC data are referenced to mean lower low water (mllw) based on NOAA specifications that require transfer of tidal datum based on comparisons of simultaneous tide measurements collected at a gauge near the survey site and an established gauge (MapTech 2000). In most areas, the distance between adjacent points ranges from 300 m near shore to 1,500 m farther offshore. Exceptions are the navigation channels at Mobile Pass, AL, Pensacola Pass, FL, and the Panama City Entrance Channel, FL. In these areas the data density approaches 30 m.

The Mobile District's Irvington Site Office provided the second type of data included in the RSM baseline data set. The data take the form of navigation channel condition surveys collected using a single-beam echosounder. This type of data was included in the baseline for Mobile Pass and Perdido Pass, both located in Alabama. These data were originally referenced to mllw using tidal gauges at the passes. The survey coverage includes only the authorized navigation channel, with data points collected in profile lines spaced approximately 100 m apart along the length of the navigation channel. Data spacing along the profile lines is sub-meter. These data were collected in the spring of 2000.

The final type of data included in the RSM baseline is that collected by the Corps SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system (Lillycrop, Parson, and Irish 1996). These data were collected at a density of 4 m horizontally for project condition surveys at East Pass, Pensacola Pass, Panama City, and Perdido Pass. The project condition surveys were collected for the Mobile District. Survey coverage included the navigation channel, ebb and flood shoals, and adjacent shorelines and offshore areas. For these surveys, depth data were collected relative to the water surface and were referenced to tidal gauges in each of the inlets. The tidal gauges were set relative to NOAA tidal benchmarks in the area.

In addition to the SHOALS project condition surveys, SHOALS shoreline surveys were also included in the RSM baseline data set. SHOALS data have been collected for the entire coastline of the RSM demonstration region. The Florida Department of Environmental Protection (FLDEP) commissioned SHOALS data extending from the Panama City Entrance Channel to Apalachicola Bay, FL, to support coastal erosion monitoring. The data were collected relative to a short baseline of NOAA benchmarks relative to National Geodetic Vertical Datum 1929 using kinematic GPS. The remaining coastline was surveyed by SHOALS as part of the RSM baseline initiative. These data were collected relative to the water surface and were referenced to tidal benchmarks in the area by interpolation between the benchmarks. These last two data sets were collected at a density of 8 m. The surveys followed the coastline, covering 300 m of inshore dry beach and 800 m of offshore bathymetry.

Each of the data sets previously listed were converted to the same horizontal and vertical datums. The horizontal datum chosen by the user is Universal Trans Mercator (UTM) projection defined by the North American Datum 1983 (NAD83). The vertical datum chosen by the user is North American Vertical Datum 1988 (NAVD88).

The baseline data set represents the most recent data for each part of the demonstration region. These data supercede all other data for that area. For example, near East Pass, FL, the baseline data set includes NGDC data, the RSM SHOALS shoreline data set (collected in 2000), and a SHOALS project condition survey (collected in 1997). The NGDC data is superceded by the more recent SHOALS surveys. So, the NGDC data retained for the RSM baseline data set only covers the offshore areas beyond the extent of the SHOALS surveys. The SHOALS project condition survey of 1997 includes data for the flood and ebb shoals, adjacent beaches and inlet throat at East Pass. The RSM SHOALS shoreline data set collected in 2000 covers an area along the shoreline extending from 300 m onshore to 800 m offshore. The 2000 data set supercedes the 1997 data set in this alongshore swath. The 1997 data for the flood and ebb shoals and inlet throat that lie outside of this swath are retained for the baseline data set.

A graphical representation of the data retained in the RSM baseline data set near East Pass, FL, is shown in Figure 1. The triangles shown in Figure 1 represent individual NGDC data points, while the 4- to 8-m density SHOALS data sets are represented by filled polygons.

**Aerial and oblique photography.** Both aerial and oblique photos are included in the RSM GIS. All aerial photography currently included in the RSM GIS was provided to the Spatial Data Branch ortho-rectified and of various geographic projections (See Figure 2). The individual images were tiled together (creating a mosaic) using the Image Analysis extension of ArcView. Mosaics were then imported into ArcINFO, converted into grids, and reprojected to the desired projection of the RSM GIS project. The projected grids were converted back into image files and compressed using Multiresolution Seamless Image Database (MrSID) software.

Oblique photographs, along with corresponding descriptions, were provided to the Spatial Data Branch in hard copy form. The photos were scanned and saved in JPEG file interchange formats. Photo descriptions were typed and saved as text files. Through the *Historical Photos* application inside the RSM GIS, oblique photos are viewed and printed with corresponding descriptive data.

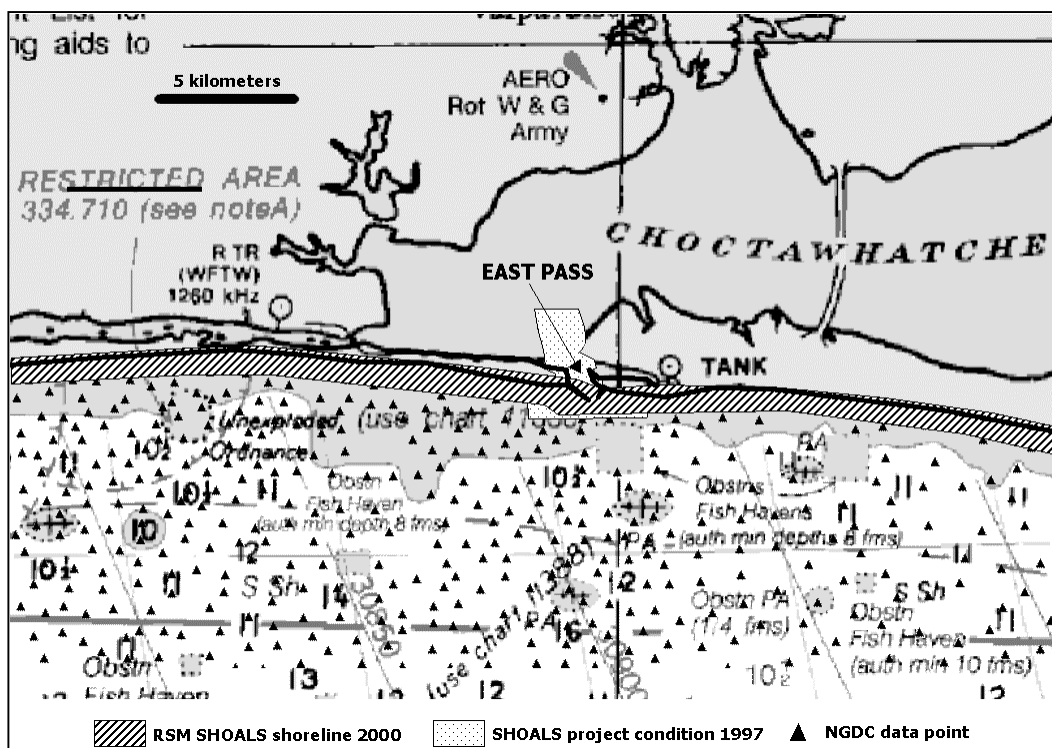


Figure 1. East Pass, FL. Graphical representation of data retained RSM baseline data set. Triangles represent actual NGDC data points SHOALS 4- to 8-m density data sets are represented by filled polygons



Figure 2. Aerial photo mosaic built for the area near Perdido Pass, AL

**Dredged material records.** Historical dredged material records are stored in a customized database. The database stores information regarding dredging history for each of the nine Federal navigation projects in the region. Every known dredging event is included in the RSM GIS dredge material database, along with associated removal sites, dredge material

quantities, placement sites, dredge contractors, and costs associated with the dredging contract. This information was collected from the Mobile District's Operations Division's Irvington and Panama City Site Offices. The original form of the information was as 3- x 5-in. note cards.

**Digital nautical charts.** NOAA nautical charts serve as the background for all other graphic entities built into the RSM GIS. These nautical charts were obtained from MapTech-distributed CD's. Three steps were required to prepare the digital nautical charts for inclusion in the RSM GIS. First, the charts were reprojected from MapTech's proprietary .kap format into a UTM83 projection using the *Chart Reproject* DOS utility available through the NOAA Web page. Second, the .kap files and their associated .bsb files were imported into ArcView and converted into the Tagged Image File Format (TIFF) with corresponding world files. This process was achieved using the Chart Reproject extension to ArcView, also provided by NOAA. Finally, the TIFF charts were cleaned to remove extraneous graphics and text as well as colorized to produce an accurate depiction of a nautical chart. This last step was achieved using the Paint Shop Pro image editor.

**Generic GIS data.** The U.S. Census Bureau releases extracts from the Census Topologically Integrated Geographic Encoding and Referencing (TIGER) database. The database is built on a county-by-county basis. For each county, TIGER/Line files include roads, railroads, hydrography, transportation information, power lines, pipelines, municipal boundaries, landmarks (schools, churches, parks and cemeteries), and key geographic locations such as shopping centers and factories (U.S. Census Bureau 2000). These data are released in GIS format and are directly importable into the RSM GIS, provided that they are in the proper projection. In the case of the RSM GIS, generic GIS data was projected into UTM83 through the Projection Utility of ArcView.

**Data Manipulation and Display Using ArcView:** ArcView and its extensions provide a great deal of data manipulation capability. This section outlines the use of built-in ArcView functionality for the creation of new coastal entities like the mean high water line and bathymetric contours.

**Shorelines.** Shorelines were created directly in ArcView. The shoreline was determined from the position of the debris line on the ortho-rectified aerial photographs. The debris line often denotes the location of mean high water (mhw), which is the desired shoreline for most coastal applications. The shoreline was delineated using heads-up digitizing in ArcView. The position of the debris line on the ortho-rectified aerial photographs was marked approximately every 15.24 m (50 ft). Through the X tools extension in ArcView, a linear interpolation was performed between each point to create the mhw shoreline.

**Triangulated irregular network.** Using an ArcView extension called 3D Analyst, a triangulated irregular network (TIN) was created from each of the hydrographic and topographic data sets included in the RSM GIS, including the baseline data set. TINs allow RSM data users to use these data sets as surfaces, rather than as two-dimensional data points with an elevation attribute. The surfaces allow for more accurate volume computations between data layers and are included as a data layer in the GIS.

**Grids.** 3D Analyst was also used to create a grid of each data set. A grid is a set of regularly spaced data points created from a set of irregularly spaced data points, like the topographic and hydrographic data sets. In the RSM GIS, grids were created from TINs to accurately represent elevation changes about the surface. Grids are used to facilitate calculations between data sets and volume computations. At each XY grid point an elevation is interpolated based on the elevation of the TIN at that same XY grid point. Each grid has been assigned a color scale based on elevation of the grid points. This colorizing of the grid points has the effect of creating color-filled contours for each data set. The grids are included as a data layer in the GIS.

**Contours.** Linear contours are also included as a layer in the RSM GIS. The contours were created using 3D Analyst. The contours are spaced at 1.5-m intervals. The contours are drawn based on the elevations given by the grid surfaces.

**Creating Custom Applications for ArcView:** Several custom applications have been written to extend the capability of ArcView to meet RSM specific goals. These applications are generally written in AVENUE script and Visual Basic and take advantage of ArcView and ArcView extension functionality. AVENUE is ESRI's programming language.

**Oblique photo tool.** Aerial photography and oblique photography often contain valuable qualitative information regarding the condition of beaches, dunes, offshore shoals, and other coastal features. Oblique photography, generally taken with a standard camera from the beach itself, from nearshore buildings, or sometimes from the air, cannot be integrated into a GIS because it lacks positioning information. Aerial photography can be integrated with a GIS if necessary rectification information is available such as camera angles, which are related to aircraft roll and pitch. However, especially with older aerial photography, often the only information available is the contact print itself.

To include these valuable photos in the GIS, even though no positioning information is available, an oblique photo tool was created that hotlinks these photos to the areas in which they were taken. For example, several photos have been collected at East Pass, FL, that cannot be rectified for input into the GIS. The oblique photo tool allows the RSM GIS user to select a location. Available photography for that location is displayed with relevant information.

An example of the oblique photo tool is shown in Figure 3. In the dialog, a small, or thumbnail version of a photo taken at East Pass, FL, is displayed. By clicking the *Full Size* button, users can access a larger version of the photo. All relevant information stored in the photo database is displayed to the right of the photo. This includes the date of the photo, the file the photo is stored in, and a caption describing the photo.

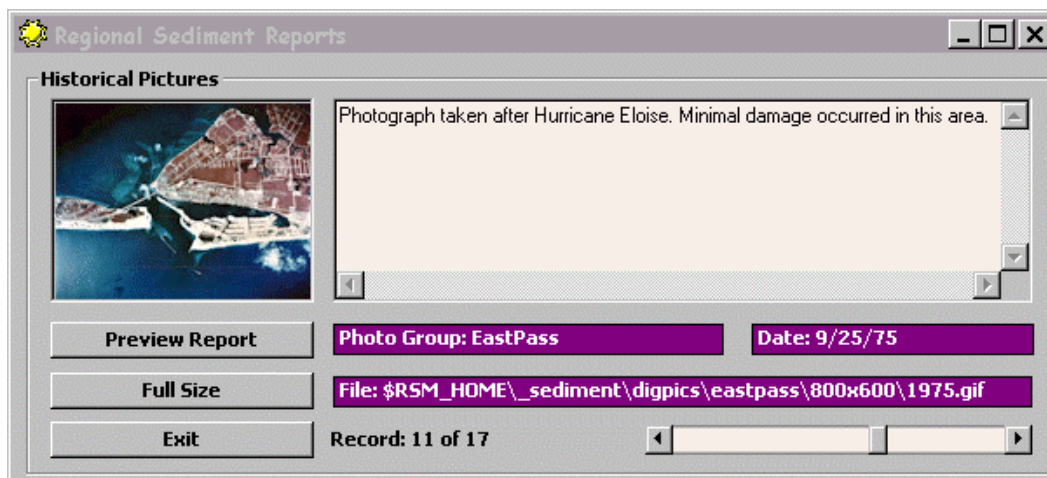


Figure 3. Custom oblique photo viewing tool built for the RSM GIS. The left side of the dialog shows a thumbnail view of a photo taken at East Pass, FL, while the right size contains the photo location, date, and a caption stored for the photo

**Dredge data reporting tool.** The dredge material database is accessed through the dredge data reporting tool. The reporting tool calls up all known dredging events from the dredge material database. The user may access a *Dredging Report* by selecting an event from the scroll-down list. The user may also select a particular navigation channel from the spatial domain of the RSM GIS and view reports for every event within that particular channel.

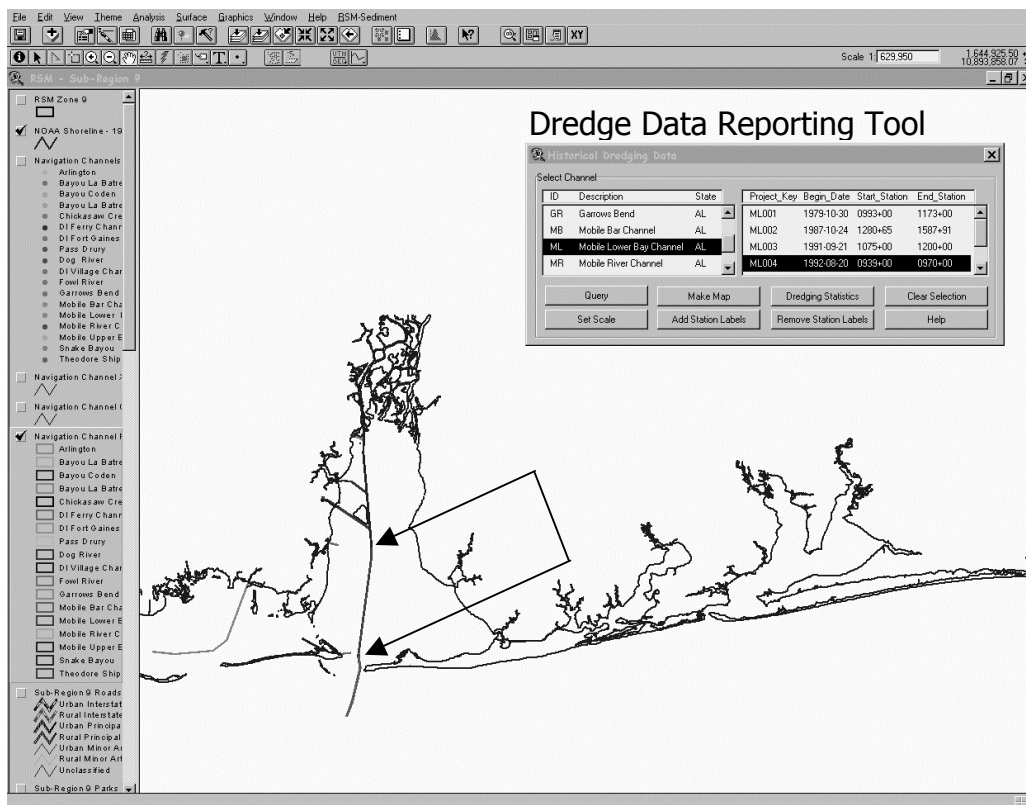
An example of a dredge data report is shown in Figure 4. Figure 4a shows the spatial domain of the RSM GIS near Mobile Pass, AL. Visible in the domain are the shoreline and navigation channels in this area. The dredging event highlighted in the dredge data reporting tool (shown blacked out) is linked to the channel section highlighted in the main window of Figure 4a (denoted by arrows). The dredge data reporting tool then uses data extracted from the dredge material database to fill a dredging report. A portion of a dredging report is shown in Figure 4b.

**Profile tool.** Beach profiles have been collected as part of the coastal monitoring for the State of Florida for many years. Part of the baselining effort for the RSM Demonstration Program included the collection of beach profiles along the entire coast of Alabama. To compare this data with higher-density data sets, like SHOALS or multibeam data sets, users must be able to view profiles extracted from the higher density data sets at locations where historical profiles were collected.

The profile tool allows the user to extract profiles from the higher density data sets. The profiles may be extracted along hand drawn line objects. The profile tool creates a set of elevations along a line based on the grid surfaces included in the GIS.

An example profile tool is shown in Figure 5. Figure 5a shows the spatial domain of the RSM GIS near East Pass, FL. Visible in the domain are the shoreline in this area, the grid surface for a SHOALS data set collected in at East Pass in 1996, and a solid line for which a profile will be





a. RSM GIS spatial domain near Mobile Pass, AL. This view includes the shoreline and navigation channels in this area

## Dredging Report - Historical Record - Regional Sediment GIS

**Project Key:** ML004

Printed: 30-Mar-2001

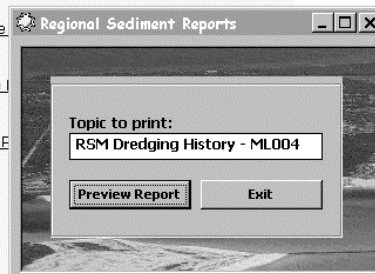
### Project Data:

<b>Project</b>	<b>Start Station Location</b>	<b>Disposal Area</b>
Mobile Lower Bay Channel	0939+00	
<b>Dredge Name</b>	<b>End Station Location</b>	<b>Contractor</b>
Bucket Dredge 54	0970+00	Great Lakes Dredge & Dock Co.

### Dredging Statistics:

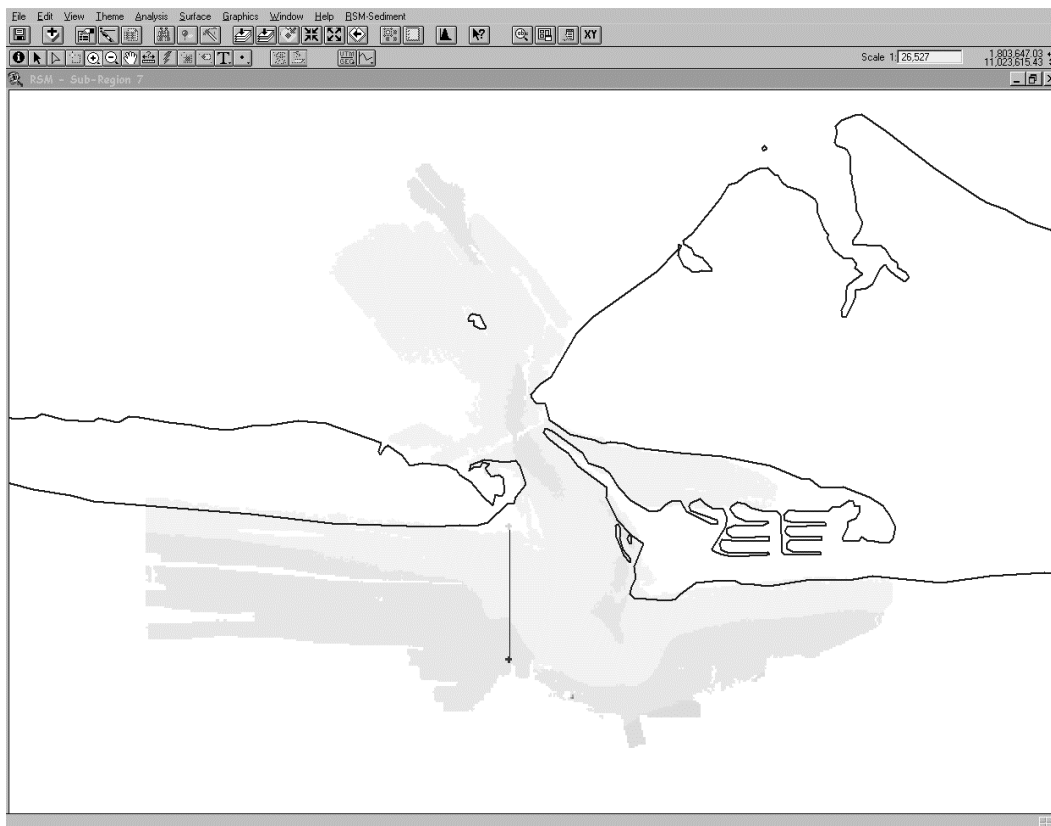
<b>Diesel Horsepower</b>	<b>Pipeline Size In</b>	<b>Gross Hourly Digging CYDS</b>	<b>Avg Daily Digging Hours</b>
		1,333.80	13
<b>Cubic Yards Gross</b>	<b>Net CYDS Per FT</b>	<b>Total Operating Time Hours</b>	<b>Total Dredge Advance Ft</b>
254,972	15.71	1,161	34,670
<b>Cubic Yards Net</b>	<b>Gross CYDS Per FT</b>	<b>Total Digging Time</b>	
173,759	23.55		
<b>Max Swim Pipe Ft</b>	<b>Max Floating Pipe Ft</b>	<b>Max Shore L</b>	
<b>Min Swim Pipe Ft</b>	<b>Min Floating Pipe Ft</b>	<b>Min Shore F</b>	

Remarks

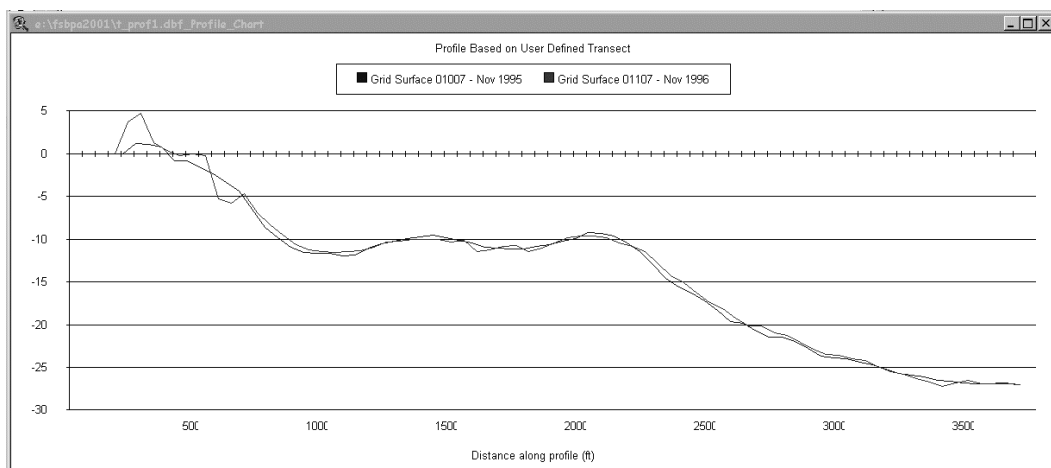


b. A portion of the dredging report filled with data from the dredge material database

Figure 4. Dredging Report tool created for RSM GIS



a. Spatial domain of the RSM GIS near East Pass, FL. This view includes the shoreline in this area, the grid created for the 1996 SHOALS data set, and a line where a profile is desired



b. Profile viewing window, where a profile is displayed for the November 1995 SHOALS survey and the 1996 SHOALS survey

Figure 5. Profile tool created for RSM GIS

extracted. Figure 5b shows the profile viewing window, where a profile is shown for both the November 1995 SHOALS data set and the 1996 SHOALS data set.

**Compute volumes tool.** The compute volumes tool gives RSM engineers and scientists the capability to compute volumes between data sets. The volumes are computed based on the grids created from the original data sets. The user may compute a volume by drawing an area (polygon) for which a volume is desired. At each grid point, an elevation difference is calculated between the two data sets. The volume is determined by integrating the differences over the areas they represent. The volume for the designated area is reported in a pop-up window. The differences are stored as a data layer in the RSM GIS.

An example showing the computed differences is shown in Figure 6. This view shows the spatial domain for the RSM GIS near East Pass, FL. Visible in the domain are the shoreline and the difference grid computed during a volume calculation. The difference grid is shown in the lower central portion of the view. The black and dark gray grid cells are areas of positive difference, or accretion. The lighter gray areas are areas of negative difference, or erosion.

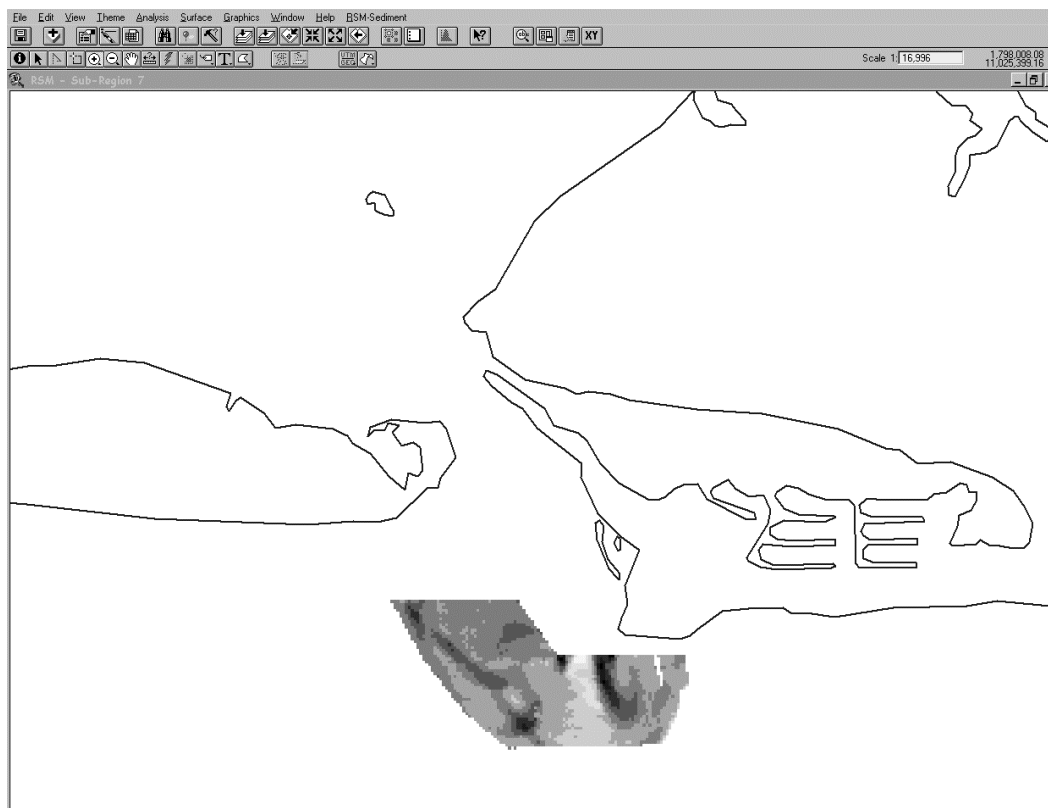


Figure 6. Volume tool created for RSM GIS. This figure shows the spatial domain for the RSM GIS near East Pass, FL. The view includes the shoreline and the difference grid computed during a volume calculation. The black and dark gray grid cells are areas of positive difference, or accretion. The lighter gray grid cells are areas of negative difference, or erosion

**Additional RSM tools.** Five additional tools created specifically for the RSM are the RSM theme tool, a dynamic search tool, a coordinate conversion tool, and two printing tools. The theme tool allows users to select a group of themes, or data layers, to add to a view at a single time. For instance, all the themes in the area surrounding East Pass, FL, may be added as a single group. The dynamic search tool allows the user to search for a specific feature within a single theme. The coordinate conversion tool allows the user to convert between UTM and geographic coordinates. The printing tools allow the user to automatically print the current view or select feature attributes to output to the printer.

**Conclusions:** The RSM GIS provides engineers and scientists with tools to both visualize spatial data and perform engineering analyses. Data visualization improves understanding of potential sediment transport pathways. Engineering analyses provide exact quantities of change in shoreline position and sand volumes. These two pieces of information are required to calibrate the numerical models upon which regional sediment management concepts depend.

**NUMERICAL MODELS FOR RSM:** RSM requires identifying and quantifying pathways and patterns of sediment movement, and using best management practices to preserve sediment and financial resources. Regional numerical models are tools to aid decision-makers in alternative selection for future activities to minimize or improve impacts on all elements of the littoral system. An understanding of regional geomorphology and prediction of long-term regional climatic changes and their impacts on the watershed and coastal processes are also necessary for determining the best RSM practices.

This section gives a general overview of the regional setting on the south shore of Long Island, NY, and of the numerical models that can be used in the evaluation of regional sediment management. With the exception of one model, the ADvanced CIRCulation Multi-Dimensional Hydrodynamic Model (ADCIRC), these models were developed for local, project-level application, and they have been extended to the regional scale as an interim prediction tool until regional models are developed. Examples of how these models are being used at the New York District are discussed.

The south shore of Long Island faces the Atlantic Ocean. Net transport of material is to the west, toward New York Harbor, but there are strong seasonal and localized reversals of transport, especially at the inlets. The Long Island south shoreline consists of 152.88 km (95 miles) of barrier island, eroding headlands on the eastern 98.78 km (30 miles), and productive estuarine bays. There are six Federal navigation inlets on the south shore. The area has farms and parklands, and the cities of Long Beach and New York. The shoreline over the last 100 years has been impacted by both storms, which caused barrier island breaching and overwash, and human activities such as inlet stabilization and groin construction.

On south shore of Long Island, the Corps maintains six navigation channels that are each dredged every 2 to 3 years, from 152,911 cu m (200,000 cu yd) per operation at Rockaway Inlet to 764,554.9 cu m (1 million cubic yards) at Fire Island Inlet. There are a number of storm protection projects in various stages of study, including the 133.57-km (83-mile) Fire Island Inlet to Montauk Point project. The entire shoreline is covered by Federally authorized storm protection projects. Since 1995, intensive data collection efforts and an Ecosystem Restoration

program for the bays have been undertaken. Over the last 40 years, an average of approximately 229,366.5 cu m (300,000 cu yd) of material has been placed annually in the area between Fire Island Inlet and Montauk Point.

The geography of Long Island consists of headlands supplying sediment to barrier islands, which is transported to navigation inlets. The need to maintain longshore transport of material, and the need to provide material for storm damage protection projects, created a need for regional studies. The navigation inlets, shoreline protection projects, and the ecosystem concerns are interconnected. Other agencies are also concerned about regional impacts. The U.S. Environmental Protection Agency and U.S. Fish and Wildlife Service have asked the New York District to examine the cumulative impacts of the beach-fill placement and dredging activities. There are also concerns about endangered species and prevention of overwash fan development. The task now facing the New York District is to connect the project areas into a regional system using the coastal processes tools and models available.

For regional numerical modeling on Long Island, regional sediment budgets, a regional ocean circulation model, regional shoreline change models, circulation models for inlets and bays, and a regional wave model, with nested grids at the inlets, have been implemented. A requirement for the validity of the regional models is accurate input data. The New York District has been able to collect repeated high quality bathymetry of some of the inlets, long-range profiles, and aerial photography. Through an authorized data collection program in collaboration with the Coastal Inlets Research Program (CIRP), the District collected a very large data set of wave, wind, current, and water level data. Also in conjunction with these studies, the District assembled a long-term history of the shoreline and the bays, which is used to check the reasonableness of the models. Models are needed to answer the questions of wave energy and height, shoreline evolution, ocean and bay hydrodynamics, inlet sedimentation patterns and effects on adjacent beaches, and the stability of the barrier islands.

The District has used the following numerical models to develop regional understanding of natural processes, and as tools for evaluating engineering alternatives: sediment budgets and the Sediment Budget Analysis System (SBAS) (Rosati and Kraus 1999, 2001), Steady Wave (STWAVE) (Smith, Resio, and Zundel 1999), a GENeralized model for SIMulating Shoreline change (GENESIS) (Hanson and Kraus 1989; Gravens, Kraus, and Hanson 1991), the ADvanced CIRCulation Multi-Dimensional Hydrodynamic Model (ADCIRC) (Luettich, Westerink, and Scheffner 1994), an inlet stability analysis (based on Escoffier 1940; van de Kreeke 1992), the Reservoir model (Kraus 2000), and the Cascade model (Larson, in preparation). A discussion of each of the models follows.

**Sediment Budgets and SBAS:** A regional sediment budget is an accounting of gains and losses within a littoral system for a specific period of time, over both local and regional scales. Sediment budgets can range from conceptual to very detailed, depending on the quantity and quality of the littoral system change data available. Sediment budgets can be used to measure the impacts of engineering actions along a regional coastal area, as well as measure the effects of natural processes such as long-term erosion and barrier island breaching.

Rosati, Gravens, and Smith (1999) developed a regional sediment budget for the Fire Island Inlet to Montauk Point study area. The area was divided into five morphologic zones, and evaluated over a number of time periods. The net longshore transport rates for various conditions, and uncertainties in sources and sinks such as bluff erosion, were integrated into the budgets developed for historical and existing conditions. A regional sediment budget for all of Long Island is being developed as a part of a RSM demonstration project. This Fire Island to Montauk Point sediment budget will be used to evaluate storm protection alternatives for that project. The Sediment Budget Analysis System (SBAS) (Rosati and Kraus 1999, 2001) is a PC-based system for formulating sediment budgets, and has been applied at Shinnecock Inlet, including all the sources and sinks and the sediment pathways. SBAS can be as general or specific as needed.

**Steady Wave (STWAVE):** STWAVE is a steady-state spectral wave model. It is a nearshore wave transformation model used to describe changes in wave parameters such as wave height, period, direction and spectral shape, between the offshore and the nearshore. STWAVE simulates many wave transformation characteristics, including breaking, refraction and shoaling, diffraction, wave-current interaction, and wave growth due to wind input. The nearshore wave output from STWAVE is used to develop estimates of sediment transport, and then with GENESIS, shoreline change. An STWAVE wave grid has been developed for the 133.57-km (83-mile) Fire Island Inlet to Montauk Point reformulation study (Gravens, Rosati, and Wise 1999). The wave grid was developed from recent bathymetry, applied using WIS (Wave Information Study) wave data, and verified using nearshore and offshore wave gauge data. Three computational grids were used for this nearshore model. Accounting for changes in bathymetry and coastal features, variations of net sediment transport over the domain were developed. The model was applied to evaluate the changes in transport caused by dredging offshore borrow sites.

The LISHORE project has implemented STWAVE regionally along the Long Island coast (Grosskopf et al. 2001). LISHORE is supporting wave gauges that provide validation data for numerical modeling and real-time documentation of wave conditions. The model is configured on a coarse resolution grid (1 nautical mile) along the entire island that provides boundary wave spectra for the finer, nested grids with resolution of 50 to 100 m at Shinnecock and Jones Inlet. The application of STWAVE along the entire regional domain provides insight into wave-driven processes at a variety of spatial scales, which are critical to defining the regional sediment budget and impacts of engineering on that budget.

**GENESIS:** GENESIS is a one-contour-line beach evolution model. GENESIS calculates longshore sand transport rates and resulting planform shape of the modeled coast at short time intervals over a prescribed simulation period. The effects of coastal structures and other planform changes to the beach can be evaluated by the model. For the Fire Island to Montauk Point study, the GENESIS model was configured for application to three analysis reaches within the study area, each from 24.14 to 48.28 km (15 to 30 miles) long. The area includes three inlets, as well as a field of 16 groins at Westhampton. Project alternatives for the Fire Island to Montauk Point study, such as widened beaches, and the addition or removal of coastal structures, will be evaluated, based on the configured GENESIS model. Having a regional shoreline change model will provide answers to questions of the regional impacts of the project alternatives.

**ADCIRC:** ADCIRC is a two-dimensional, depth-integrated finite-element hydrodynamic model developed with the capability of operating over a wide range of grid element sizes. Fine resolution can be defined for accurate calculation of flow-through channels and around coastal structures. The New York District has applied ADCIRC in large- and small-scale studies. A regional tidal circulation grid has been developed that includes the Atlantic Ocean, Long Island Sound and New York Harbor, and the six inlets and the associated bays located on the south shore of Long Island. Resolution is increased from the ocean toward the coast, with greatest node density in the bays and inlets. The regional propagation of the tidal wave around Long Island was modeled using ADCIRC. Differences in water-surface elevations play a key role in the circulation of water through the south shore estuary system, which in turn impacts inlet hydrodynamics and inlet sediment transport patterns.

Because of concerns regarding borrow area sources for a shoreline protection project just west of Shinnecock Inlet, in coordination with the CIRP, a model was developed to predict impacts of using the flood shoal as a borrow source (Militello and Kraus 2001). Fine detail was implemented in the ADCIRC model mesh for the Shinnecock study area, for resolution of the channels, jetties, and shoals. Sixteen alternative configurations of flood shoal mining were modeled. ADCIRC has robust wetting and drying algorithms to simulate the inundation and exposure of the flood shoal. Based on the impacts calculated by the model, a final recommended plan for the flood shoal mining was developed. By having this tool, the District was able to show the local land trustees how changes in the bathymetry would change the current patterns. Without this tool the District would not have been able to recommend using the flood shoal as a borrow source.

**Inlet Stability Analysis:** A multiple inlet stability analysis was used for the evaluation of barrier island breaching, to determine whether a stabilized inlet or a newly formed inlet would remain open after a breaching event (Headland et al. 1999). The condition of the inlet/bay system can have great impacts on local and regional sediment transport, including displacement of barrier island sediments, burial of bay habitat, interruption of littoral drift, and increased shoaling or closure of inlet navigation channels. The analysis was based on inlet closure theory as described by Escoffier (1940) and van de Kreeke (1992). For each of the barrier-bay systems, closure surfaces considering the areas of the inlet and the breach, and corresponding flow velocities were developed. The overlapping of the two equilibrium flow curves, is plotted separately to determine if both the inlet and the breach will close, if the inlet will close, if the breach will close or both will remain open. Empirical data of historical breaches on Long Island, especially breach cross-sectional area, were very important to this analysis.

**Reservoir Model:** The Reservoir model (Kraus 2000) is a mathematical model for calculating the volume and sand-bypassing rate at ebb-tidal shoals. The analytical solution for volume changes and bypassing rates depends on the ratio of input longshore sand transport rates and the equilibrium volume of morphological features of the ebb shoal, the bypassing bar and the attachment bar. The model gives explicit expressions for the time delays in sand bypassing associated with creation and growth of inlet features. The Reservoir model was applied at Shinnecock Inlet to evaluate consequences of mining the flood shoal (Militello and Kraus 2001). An extended generalized model that is solved numerically also includes the flood shoal, the inlet entrance channel, and the exchange of sediment between these and other sand bodies.

**Cascade:** The Cascade model is an emerging numerical simulation model aimed to bridge the gap between a sediment budget over a regional extent and the application of GENESIS over the individual reaches comprising the region. GENESIS cannot directly span over inlets. Within Cascade, sediment storage and bypassing are represented at the inlets between reaches through the Reservoir model. Cascade explicitly represents sediment-transporting motion on different spatial and temporal scales, cascading sediment transport processes to and from regional to local scales. The regional and local contours are represented, as are the ebb shoals for calculation of waves and longshore sediment transport.

**Conclusions:** Regional applications of numerical models can help define the littoral system and can be used to evaluate natural and engineering impacts to the system. Regional numerical modeling can be initiated by gathering all available accurate data on waves, shoreline change, engineering activities, natural events such as breaching, sediment type, and circulation patterns. The next step is to develop a conceptual sediment budget. From that base, SBAS can be applied to develop flexible, spatially variable sediment budgets, to determine areas where more data are needed. If there is adequate funding, and good regional data including wave and tidal information, the models described in this section can assist in RSM responsibilities and objectives.

**ADDITIONAL INFORMATION:** This CHETN was written by Mme. Jennifer M. Wozencraft, Lynn Hardegree, Lynn M. Bocamazo, Julie D. Rosati, and Dr. Jack E. Davis. Ms. Wozencraft and Ms. Hardegree work for the Mobile District, and Ms. Bocamazo works for the New York District. Ms. Rosati and Dr. Davis work at the U.S. Army Research and Development Center (ERDC), Coastal and Hydraulics Laboratory. The research was jointly supported by the Coastal Inlets Research Program, Inlet Channels and Adjacent Shorelines Work Unit, and by the Coastal Sedimentation and Dredging Program, Regional-Scale Modeling Morphology Change and Sediment Transport Work Unit. Questions about this CHETN can be addressed to Ms. Rosati (601-634-3005, Fax 601-634-4314, e-mail: [Julie.D.Rosati@erdc.usace.army.mil](mailto:Julie.D.Rosati@erdc.usace.army.mil)). Note that references to commercially available products does not constitute endorsement by the U.S. Army Corps of Engineers.

This CHETN should be cited as follows:

Wozencraft, J. M., Hardegree, L., Bocamazo, L. M., Rosati, J. D., and Davis, J. E. (2001). "Tools for regional sediment management," ERDC/CHL CHETN-XIV-2, U.S. Army Engineer Research and Development Center, Vicksburg, MS.  
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